LCA Methodology

On the Possibilities to Apply the Result from an LCA Disclosed to Public

Martin Erlandsson* **and Lars-Gunnar Lindfors**

IVL Swedish Environmental Research Institute, Box 21060, SE-100 31 Stockholm, Sweden

* **Corresponding author** (martin.erlandsson@ivl.se)

DOI: http://dx.doi.org/10.1065/lca2003.02.105

Abstract

Aim, Scope and background. Given the communication limitation of a damage-oriented approach, the question addressed in this paper is how normalisation can be developed instead. Normalisation of product service systems without value choices is, in accordance to ISO 14042, suitable for external communication. Reason normalisation approaches use a geographically-defined baseline year of emissions, optionally combined with politically established target emissions (Guinée 2002, Stranddorf et al. 2001). In contradiction to these approaches, this paper aims to draw up the general structure of an alternative normalisation procedure. The normalisation procedure suggested here is based on environmental quality objectives (EQO), in order to streamline the result to include as few output parameters as possible, without compromising the scientific robustness of the method.

Main Features. This article describes a normalisation procedure based on environmental quality objectives. Comparison between this approach and a damage-oriented approach is conducted. The relevant working area concerning dose and effect is evaluated. Then a discussion is conducted focusing on the trade-off necessary to achieve an integrated category indicator, covering the following issues; model reliability, user applicability and the unambiguously of the result.

Result. A damage-oriented approach will have to take into account all the defined consequences from all impact categories that affect the safeguards in parallel. In other words, each impact category indicator and its potential effects on all safeguards must be evaluated and accounted for. In the case where a single category indicator cannot be found without utilising value choices, a number of category indicators will then have to constitute an intermediate category indicator result, where weighting must be applied in order to streamline the result.

In contrast to the above approach, the suggested normalisation procedure utilises the precautionary principle with respect to the essential EQO in order to achieve a category indicator result, called a critical load category indicator result. In practice, this means that the number of figures in an LCIA-profile based on critical load will always be the same as the number of impact categories.

Conclusions. The suggested EQO normalisation procedure forms a set of critical loads per impact category, where each is defined by a critical load function where linearity is defined between a zero load and the critical load. This procedure will affect the temporal resolution and the field of application of the LCIA method. The positive aspect is that the suggested normalisation procedure renders the method applicable for long-lived products like, for example, buildings or other infrastructures. This aspect is gained by reducing the damage-oriented resolution. Consequently, for long-lived products where the main environmental loads will appear in the future, it is hard to assess by a damage-oriented LCIA method (if all boundary conditions are not assumed to be fixed). The EQO normalisation method will, in this respect, improve the overall reliability of the outcome of an LCA when long-lived products are assessed. For short-lived products, adequate boundary conditions can be achieved, and for this reason a damage-oriented approach will have the possibility to address current consequences. Nevertheless, a damage-oriented approach working area is not applicable beneath thresholds unlike the EQO normalisation procedure. The most effective decision support of short-lived products is therefore achieved when both approaches are applied.

Outlook. A complementary paper will be produced where the described normalisation procedure is exemplified in a case study, with special interest on assessment of chemical substances.

Keywords: Critical load; damage function; environmental quality objectives (EQO); LCA communication obstacles; LCA disclosure to public; life cycle assessment (LCA); life cycle impact assessment (LCIA); normalisation; precautionary principle

Introduction

Information from life cycle assessments (LCA) is often described as being scientifically based. This is probably one reason why LCA is regarded as one of the most important life-cycle based tools in contexts such as life cycle management (LCM 2000) the Europeans Commission's approach for Integrated Product Policy (IPP) (EU 2001a, EU 2001b) and in third party certified product declarations (e.g. GEDnet 2002).

Whilst LCAs are scientifically-based, they are not necessarily precise. In order to be precise, an enormous amount of parameters would be required to describe complex phenomena such as the environment cause effect chains. In reality, lack of knowledge of these parameters makes a precise assessment impossible. For this reason, simplifications are introduced to the model. As a result, boundary conditions have to be valid in order to achieve reliable results from the applied model. The model simplifications or estimations must therefore be defined, justified and verified in a transparent way. When non-specialists use procedures such as impact assessment methods in an LCA, the limitations and context of this decision support system must be clearly and convincingly described.

The mandatory parts of the LCA environmental assessment, described in the ISO standard 14042 "... – *Life cycle impact assessment*" (LCIA) (ISO 2000) are strictly regarded as

© ecomed publishers, D-86899 Landsberg, Germany and Ft. Worth/TX, USA • Tokyo, Japan • Mumbai, India • Seoul, Korea

an issue handled by natural science. This is appropriate when the aim is to analyse or estimate the potential environmental effect of emissions from a product system in the life cycle inventory (LCI). This leads us to model the environmental fate of the substances emitted and ideally express the contribution of these loads to different damage functions (Udo de Haes et al. 1999). A crucial disadvantage of this kind of damage-oriented approach is that value choices are necessary in order to interpret the results and cannot be removed by further scientific development (Udo de Haes and Jolliet 1999). According to ISO 14042, the results of this kind of LCIA are not appropriate for external communication. Under the title 'Comparative assertion disclosed to the public' it is established in ISO 14042 that "Weighting, ..., shall not be used for comparative assertion disclosed to public". Under Note 4, it is stated that a comparative assertion is an environmental claim regarding the superiority or equivalence of one product versus another product that performs the same function. Furthermore, the standard makes a clear difference between assumptions, other operations and value choices that include subjectivity. These aspects are often handled by disciplines other than environmental science.

Given the communication limitation of a damage-oriented approach, the question addressed in this paper is how normalisation can be developed instead. Normalisation without value choices of product service systems is, in accordance to ISO 14042, suitable for external communication. Reason developed normalisation approaches use a geographically defined baseline year of emissions, optionally combined with politically established target emissions (Guinée 2002, Stranddorf et al. 2001). Another interesting normalisation/valuation method is developed by Umwelt Bundes Amt (Schmitz and Paulini 1999). In this method, a normalisation based on distance to political target and environmental concern was chosen for a careful ranking and grouping without actual weighting. In contradiction to these approaches, this paper aims to draw up the general structure of an alternative normalisation procedure utilising environmental quality objectives combined with the precautionary principal. However, this paper shares the same field of interest that is addressed in the elaborate UBA method, i.e. to streamline the result to include as few output parameters as possible, without compromising the scientific robustness of the method. The idea to utilise environmental quality objectives is also suggested by Brent (2002) as part of a weighting method.

1 Characteristics of environmental impact assessment in LCA

1.1 LCA and LCIA

An LCA is divided in a number of steps, defined by ISO 14040 (1997) (ISO 1998, ISO 2000b).This article concerns the life cycle impact assessment (LCIA) step (ISO 2000a).

The result from the first step of an LCA, life cycle impact assessment (LCI), is hereafter referred to as an ***LCI profile*** and includes the emissions and resources related to the functional unit. The LCIA condenses the LCI profile and assigns the environmental significance resulting from the use of the functional unit calculation (**Fig. 1**).

Environmental issues in the LCIA are divided in different impact categories (acidification, climate change, etc.), which makes it possible to convert the LCI profile to an ***LCIA profile,*** through a number of mandatory steps specified in ISO 14042 (see Fig. 1). The *LCIA profile* corresponds to the communication outcome from the mandatory part of an LCIA/LCA. Besides data quality analysis, optional elements are normalisation, grouping and weighting.

For each impact category (e.g. eutrophication) ***category endpoints*** (e.g. loss of species, algae blooming) have to be established. The ***environmental mechanisms*** behind the ***category indicator*** (e.g. deposition increase of N/P equivalen-

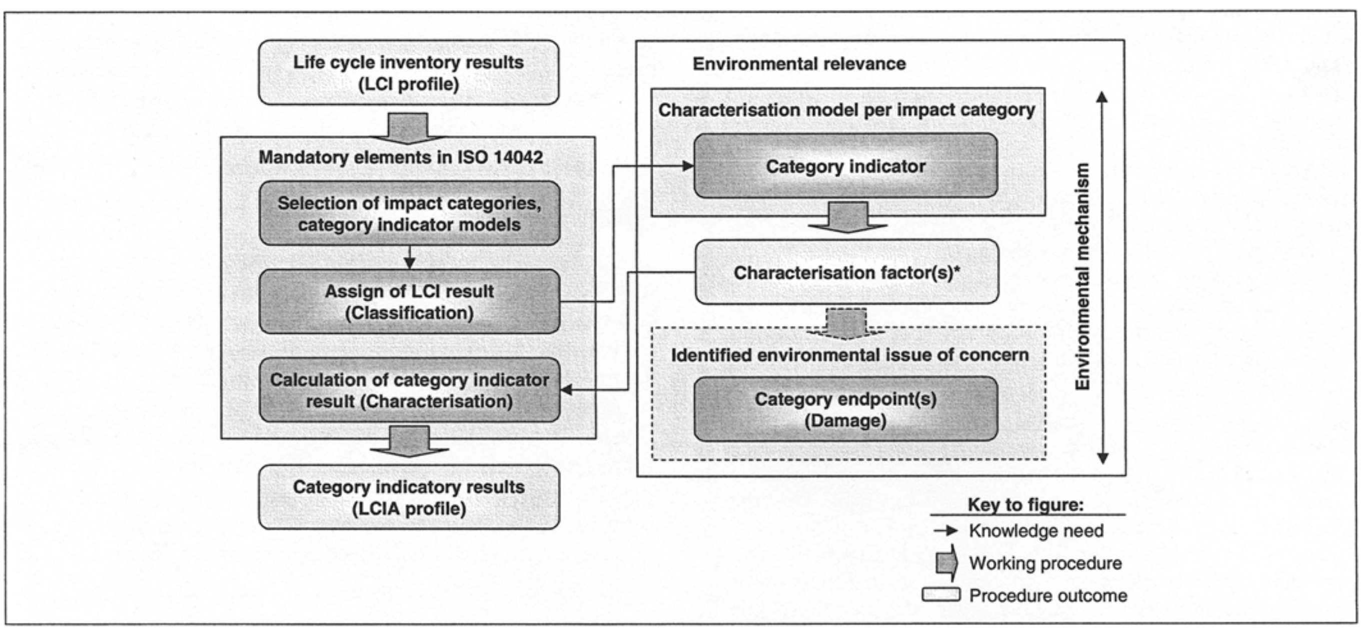

Fig. 1: Mandatory elements of LCIA according to ISO 14042, including the concept of category indicators (Integration of Fig. 1 and 2 in ISO 14042, 2000). *Different temporal and spatial resolution results in different sets of characterisation factors for the same substance (and therefore the plural form is used)

cies in the biomass) is elaborated in a ***characterisation model*** (e.g. a stoichiometric procedure which identifies the equivalence between N and P for terrestrial and aquatic system). The outcome from the characterisation model is made operational in the LCIA by ***characterisation factors*** for different substances (e.g. PO_4^{3-}/kg emission).

The consequence of category endpoints is addressed with respect to safeguards. The term *safeguard* (also called areas of protection; Consoli et al. 1993) is not defined in ISO14042, but is similar to the term *group category endpoint*. The group category endpoint is divided into natural environment, human health and resources. If these three safeguards were accepted, resources would then have to account for both natural and man-made resources in order to be compatible with this two-dimensional resource approach suggested by Udo de Haas and Lindeijer (2001).

1.2 The aim behind and beyond ISO 14042

From a user perspective, the LCIA step has two major points of interests. The first is to develop the inventory profile's environmental dimension. The second is to aggregate the result into as few figures as possible. The aim of aggregating the result sometimes into a single score index drastically affects the significance of the LCA-result. This can, however, be justified when non-specialists need to interpret the environmental profile for internal use. For this reason, it would be more correct to only address environmental issues managed by natural science in the LCIA step, and then follow up by a more comprehensive and user-friendly evaluation of the environmental profile in the life cycle interpretation phase of an LCA. During the process of interpretation, implementation of value choices should be in line with the general aim to condense the overall result, but restricted to the interpretation step. The LCI and LCIA steps should then also further constitute the environmental science-based decision support. Such development of LCA within the ISO umbrella may be a relevant issue for the revision now underway of the whole 14040-family. This weak part of the ISO standard can be explained in an historical perspective, since ISO 14043 was originally aimed at the *improvement* issues and was then converted to the *interpretation* step of an LCA during the process.

1.3 ISO 14042 opportunities

ISO 14042 indirectly outlines two strategies for addressing the assignment of relative significance to the impact categories in an LCIA profile. The first strategy is an optional choice in the standard to use normalisation and grouping of the LCIA profile for public comparative communication. In this strategy, as applied here, weighting factors are not used and ranking of impact categories is avoided. The alternative strategy is to actually estimate the damage on the safeguards such as human health, ecological health and natural resources. In theory, this should be possible, but it is not in practice. This is due to a lack of information within the LCI and the characterisation model, which would have to include non-linear damage functions in order to receive the impact category endpoint. This will also be in conflict with the line of argument within the LCA approach of 'potential environmental impacts' (read; potential environmental effect) as described in ISO 14040.

In practice, therefore, 'damage-oriented' approaches are introduced instead, e.g. Eco-Indicator (Goedkoop et al. 1998). But this approach also holds its own problem, because damage-oriented effects are not directly additive by natural science. For instance, it is impossible to assess different effects to human health like death and lifelong asthma (for example, handled in the Daly concept), because this includes value choices (Murray and Lopez 1996).

1.4 Two approaches to achieve environmental significance

We will here require that the selected impact categories should be independent from each other. Otherwise double accounting problems will occur. This independence is also a requirement for the safeguards. This implies that one should not include two impact categories covering the same category endpoint, for example, ozone formation for low as well as high NO_x background levels. In these cases only one option that corresponds to the current conditions should be chosen. Alternatively, if information from the LCI is missing, the resulting figure could be given with an indication of the level of uncertainty caused by the knowledge gap. In such a case, the same characterisation model will be applied using different sets of characterisation factors, valid for different spatial or temporal frames. Another consequence of this requirement, is that indicators like 'waste generation', as e.g. utilised in ISO/DTR 14047 Ex. 7 (ISO 2001), EDIP (Wenzel et al. 1997) and the Swedish environmental product declaration system (MSR 2000), would not be accepted in the LCIA profile. A stressor indicator such as waste to a landfill would also be rejected if the role in ISO 14041 concerning elementary flows were considered.

A category endpoint will, in reality, cause a number of effects. As indicated in Fig. 1, ISO 14042 does not actually include direct quantification of such (absolute) effects, only indicators that assign the potential effects within the LCIA-profile. The individual category endpoint effects are in reality dependent on each other, as indicated in **Fig. 2**. The dam-

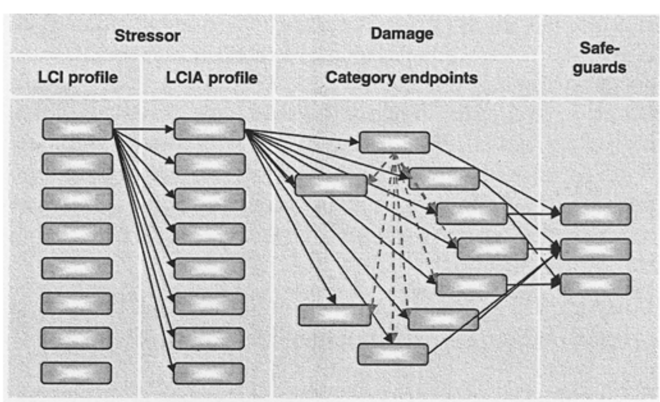

Fig 2: Principal overview of relationships between stressor and the damage defined as category endpoints in a damage-oriented approach (It is here assumed that the LCIA-profile does not include any value choices). The dotted line indicates dependencies between different category endpoints not accounted for, e.g. synergistic effects

age approach illustrated in Fig. 2, includes different potential effect related endpoints where spatial and temporal damage functions are essential. A number of operational 'damage-oriented' approaches are frequently used e.g. ExternE (1995, 1997), Eco-Indicator (Goedkoop and Spriensma 2000) and EPS (Steen and Ryding 1992, Steen 1999), and EDIP2000 (Hauschild and Potting 2001).

An alternative method to improve the environmental relevance in the LCIA step, which does not include a value choice-based damage approach, can be achieved by so-called ***environmental quality objectives*** (EQO). EQO includes estimations, which preferably should be based on scientific common knowledge, which is why the EQO will then be of a normative character. These kind of normative decisions may also include elements from social and political sciences. EQO indicate environmentally acceptable conditions that can be regarded as ecologically sustainable, defined by a ***critical load function***. Environmental ***critical loads*** based on best available techniques or best possible techniques are not considered here to be relevant for EQO, since the environmental impact relevance is not accounted for.

In order to apply EQO in LCA/LCIA, it is necessary that the critical load is expressed as a mass flow rather than a recipient concentration, etc. Such EQO are put forward in a holistic way in the so called Swedish environmental quality goals (Swedish Government 2001), which are then used for normalisation of the most common impact categories (Erlandsson 2000, Erlandsson 2001). Other approaches such as the EU's ceiling directive (EUc 2001) is a mixture of EQO and political emission targets, and does not cover all impact categories. A comprehensive record of all kinds of EQO (also called Sustainable Reference Value) and emission targets can be found in the EEA - STAR database (EEA 2002). Also the German UBA valuation method facilitates a mixture of EQO (critical load) and political emission targets per impact category as part of the assessment method (Schmitz and Paulini 1999).

The question of who has the permission to contribute to this environmental impact is an additional issue related to the EQO normalisation approach. This is a matter constantly on the political agenda. Therefore, different international agreements result in a quota system where the acceptable amount per contributor is restricted on a national level. However, it will still be a normative decision in the LCIA to decide for instance if the acceptable annual emissions contribution to climate change should be normalised per global individual citizen, or if national or regional politically acceptable quota should be applied (as according to the Kyoto protocol, etc.). Because of this specific issue, LCIA always includes some socio-economic elements, direct or indirect, in a normalisation.

When EQO are put into operation in the LCIA it was here found to be appropriate to include the ***precautionary principle*** within the normalisation step in order to streamline the result. The precautionary principle is based on the fact that the system's vulnerability is to a great extent determined by its weakest part. In this respect, acidification is determined by the safeguard ecological health and not human health, etc. A normalisation based on EQO would then facilitate the determination of the contribution to the safeguards, as illustrated in **Fig. 3** (i.e. the single line from each impact category to a safeguard). In a damage-oriented approach, in contrast, it is required that each individual contribution from an impact category (potentially) affecting all safe guards is accounted for via a number of category endpoints, as illustrated in Fig. 2.

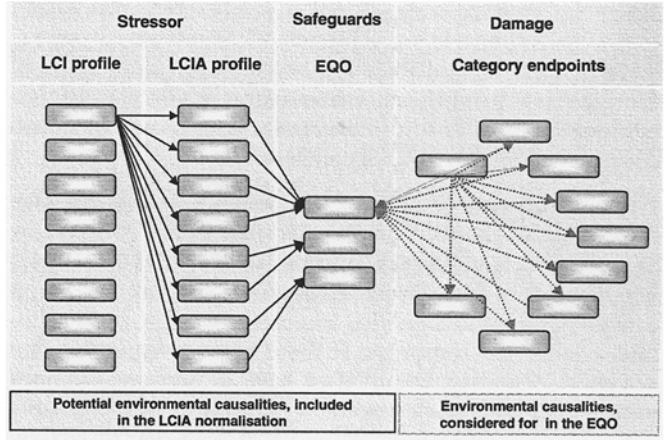

Fig. 3: A normalisation based on environmental quality objectives, including the precautionary principle, will streamline the LCIA profile without including weighting elements. Damages are indirectly accounted for via EQO (dotted lines)

A normalisation based on EQO forms a scenario where a number of acceptable environmental category endpoint conditions are safe, acceptable or tolerable on a scientific basis. The collection of all EQO together describes future sustainable environmental conditions where the safeguards are protected. This implies that the category endpoint's contribution to a safeguard must be fulfilled if the ecologically sustainable society in its turn shall be fulfilled. In that respect, the normalised impact categories contribute equally to the safeguard. In contrast, in a damage-oriented approach, it would be necessary to phase the ranking of all of the different effects included against each other, and this therefore includes elements of value choices.

1.5 EQO and critical load function in practice

A damage-oriented approach has to consider current background conditions and, from that perspective, predict the effect of an additional environmental load. For long-lived products, the background conditions vary. This has to be considered if a relevant outcome from the LCIA is to be achieved. In the normalisation approach suggested here, it would not be suitable to use current background conditions in a characterisation model, since it could cause misleading information (see example below). Instead, the future (ultimate) sustainable background conditions are used to obtain the characterisation factors in order to maintain a stringent methodology. The ecologically acceptable sustainable environmental load then has to be defined for each category endpoint, i.e. the critical load. Since EQO are used, the critical loads defined also constitute the normalisation references for the safeguards.

The definition of the EQO and critical load is by no means given once and forever. In its original definition, it includes possibilities for improvements due to additional scientific knowledge. Acidification can be used as an example. The initial concept of critical loads (Nilsson and Grennfelt 1988, Grennfelt and Thörnelöf 1992) was developed about 15 years ago when the critical load was exceeded across large parts of Europe. An EQO related to the critical load concept was derived with emphasis on the protection of forestry ecosystems. Nowadays, the areas of land where this critical load is exceeded are much smaller. In this new situation, an improved critical load concept could be argued, taking into account a broader perspective in the EQO including such aspects as the dynamics of recovery and influence of various land use protection methods (Grennfelt et al. 2001).

Another interesting outcome from the normalisation approach is photochemical ozone formation, where different characterisation factors can be found based on the current background situation (Altenstedt and Pleijel 2000). In a situation where background VOC concentrations are high, an extra emission of NO_x (acting as a catalyst) would reduce the ozone load. This situation would be described in an LCIA as 'positive' emission concerning photochemical ozone. In an LCA, this is visible by a negative characterisation factor for NO_x. However, in the suggested normalisation approach, the characterisation model is applied to a sustainable future background condition. In this case, a low NO_x and VOC background condition is taken as a reference for the critical load. This then affects both the characterisation factors for NO_x and VOC emissions, in the respect that under these conditions they will be regarded as 'negative' loads.

Parallels could be drawn with a normalisation based on EQO by using the back casting technique. In this case, the LCIA will give a result based on a scenario where the environmental critical loads are not exceeded (**Fig. 4**).

With a damage approach in mind, one could argue: "*If the analysis of the emitted substance concludes that no environmental critical load will be exceeded in reality, the substance will not contribute to any environmental impact in the LCIA profile.*"

If a damage-oriented approach is used, the 'damage function' indicated in Fig. 4 will be a relevant working area concerning the environmental effect. When running a damage-oriented approach, an extra environmental load, for example, that contributes to a concentration beneath a threshold, should then consequently not contribute to the environmental impact and the LCIA-profile. This is shown in Fig. 4 as the 'potential effect'. When this situation occurs, the risk minimisation approach will still be relevant. In this case, the normalisation procedure suggested here could then be utilised in parallel.

LCA was originally developed as a risk minimisation tool because it is a relative approach-based tool (ISO 14042). In reality, environmental loads beneath the critical load cause a potential effect for some substances, e.g. particle and ionising radiation (radon). Even if an emitted substance can be proved to have no effect beneath a threshold, this emission can be regarded as a contribution to a concentration that may exceed the threshold in the future. A normative decision can then support a decision where all emissions that potentially or actually contribute to an exceedance of a threshold shall be considered in the environmental burden. This justifies linearity between the threshold and the origin, see Fig. 4. This linearity is here referred to as a *critical load function*. This can be likened to the common sink problem, where the 11th litre of water causes the sink with a 10 litre capacity to overflow. The question is whether it is only the last litre that is responsible for the overflow. If LCA operates in the potential effect area indicated in Fig. 4 or just above the critical load, it is suggested here that all 11 litres would carry the same burden for causing the sink to overflow. This would at least be correct when the normalisation based on EQO is applied.

2 Results and Discussion

A damage-oriented approach will have to take into account all the defined consequences of all impact categories that affect the safeguards. In other words, each impact category indicator and its potential effects on all safeguards must be evaluated and accounted for. In the case where a single cat-

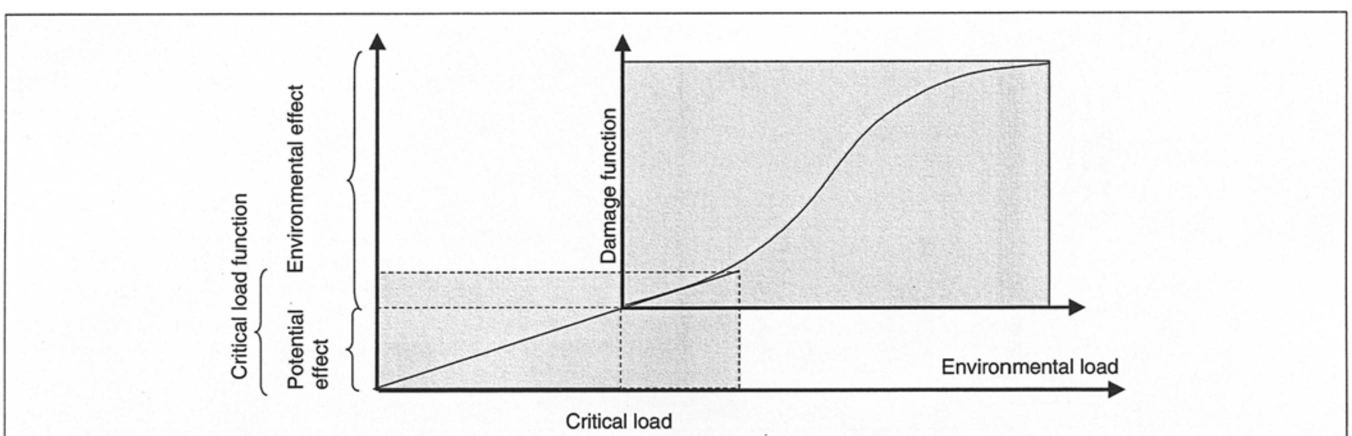

Fig. 4: The relation between environmental load and potential or defined effect described by damage functions. In the figure, the critical load is indicated, which states the reference value for the normalisation and critical load function

egory indicator cannot be found without using value choices, a number of category indicators will then have to constitute an *intermediate category indicator result.* This intermediate category indicator result will be suitable for public communication and is referred to here as a ***multi-damage** category indicator result.* Weighting can be applied to the multi-damage category indicator results for each impact category in order to form an ***integrated** category indicator result,* see Fig. 2.

In contrast to the approach above, the suggested normalisation procedure utilises the precautionary principle with respect to the essential EQO in order to achieve a category indicator result, called a ***critical load*** category indicator result. In practice, this means that the number of figures in an LCIA-profile based on critical load will always be the same as the number of impact categories.

In order to illustrate the magnitude of overall figures in the LCIA-profile, based on different category indicator results, a hypothetical example follows. In this example, the LCIA-profile uses five impact categories and each is described by only one category indicator (without introducing value choices). If each impact category affects all three safeguards, then the multi-damage category indicator result will consist of fifteen figures. Using the normalisation procedure proposed in this paper, the critical load category indicator result in the example consists of only five figures. In practice, when a damage-oriented approach is used, e.g. for human toxicity, a number of intermediate category indicator results will be adequate and, for this reason, the overall indicator result will be more than fifteen figures. On the other hand, the human toxicity impact category only affects the safeguard human health. A multi-damage category indicator result can optionally be integrated per impact category by applying a weighting procedure such as DALY's or QALY's for human toxicity.

A multi-damage category indicator result illustrates an unambiguous category indicator result. Such a profile corresponds to a relatively scientifically robust, communicable result, but with the significant disadvantage that it includes a relatively large number of figures. The multi-damage category indicator result is therefore found to have relatively low user applicability, but relatively high model reliability and unambiguity from a scientific point of view.

The multi-damage category indicator is the basis for the comparison with other approaches illustrated in **Fig. 5**. Compared to the multi-damage indicator result, the critical load result is relatively more ambiguous, due to the normative decision to apply the precautionary principle. Some model assumptions also have to be made in the critical load approach in order to evaluate a critical load based on EQO modelling. This brings about a reduction in model reliability. The overall evaluation of the critical load approach is that a drastically increased user applicability is achieved, whilst the uncertainties introduced is small.

The integrated category indicator result generates the same amount of figures in the LCIA-profile as the critical load approach. Since the result is condensed to the same amount of figures, based on the same characterisation models and covering the same impact categories, the same relative user applicability is obtained, see Fig. 5. The integrated damage category indicator results in increased user applicability. This is achieved at the cost of introducing value choices and model assumptions in order to evaluate the potential damage. Altogether, this results in increased reliability and greater ambiguity of the indicator result. The negative aspect of greater ambiguity can be justified if further weighting is desired, since this approach includes full resolution to assess the potential effect on all category endpoints (compare with Fig. 2 and the 'missing' steps in Fig. 3).

The feasible weighting based on the *integrated damage* category indicator result is here referred to as a *weighted (category) indicator result,* communicated as a *safeguard profile* (**Fig. 6**). The input to this weighting process is the integrated indicator result already described. The weighting is performed across different potential effects and quality objects of the safeguards. The weighted indicator result will always be ambiguous, since the value of the damage can be interpreted in more than one way and varies according to the foundations of the value choice.

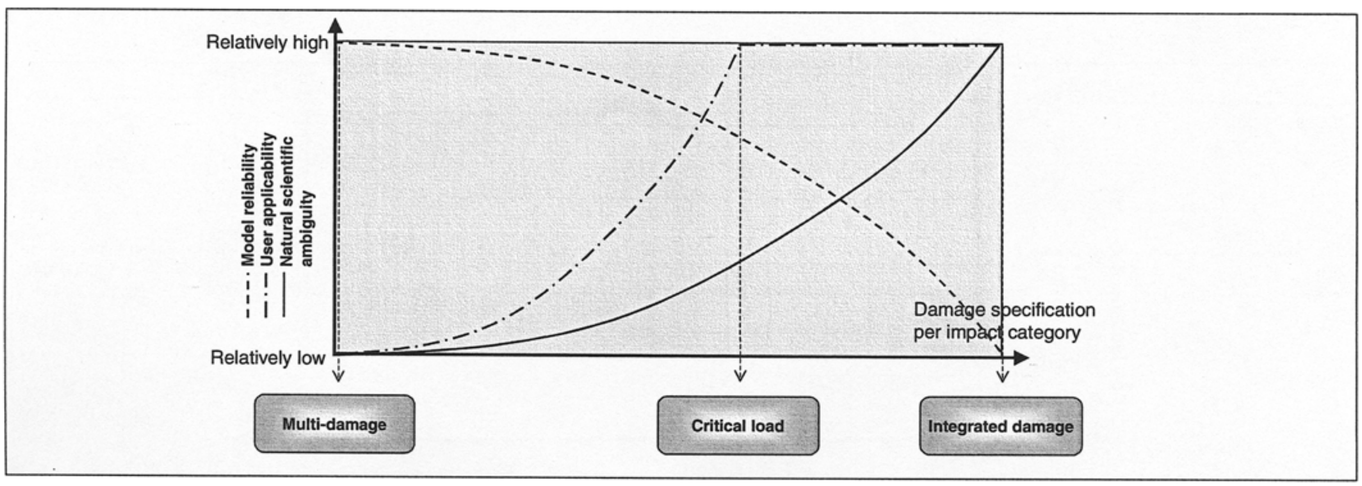

Fig. 5: Choice of the most comprehensive type of category indicator result for an impact category. Trade-off in order to achieve an integrated category indicator will reduce the model reliability (assigned by applied models and assumptions) and increase ambiguity, since elements of value choices (interpretations) will be introduced. (Inspired by a figure by Jolliet O, Hauschild M and Potting J, found in: Hauschild and Potting 2001)

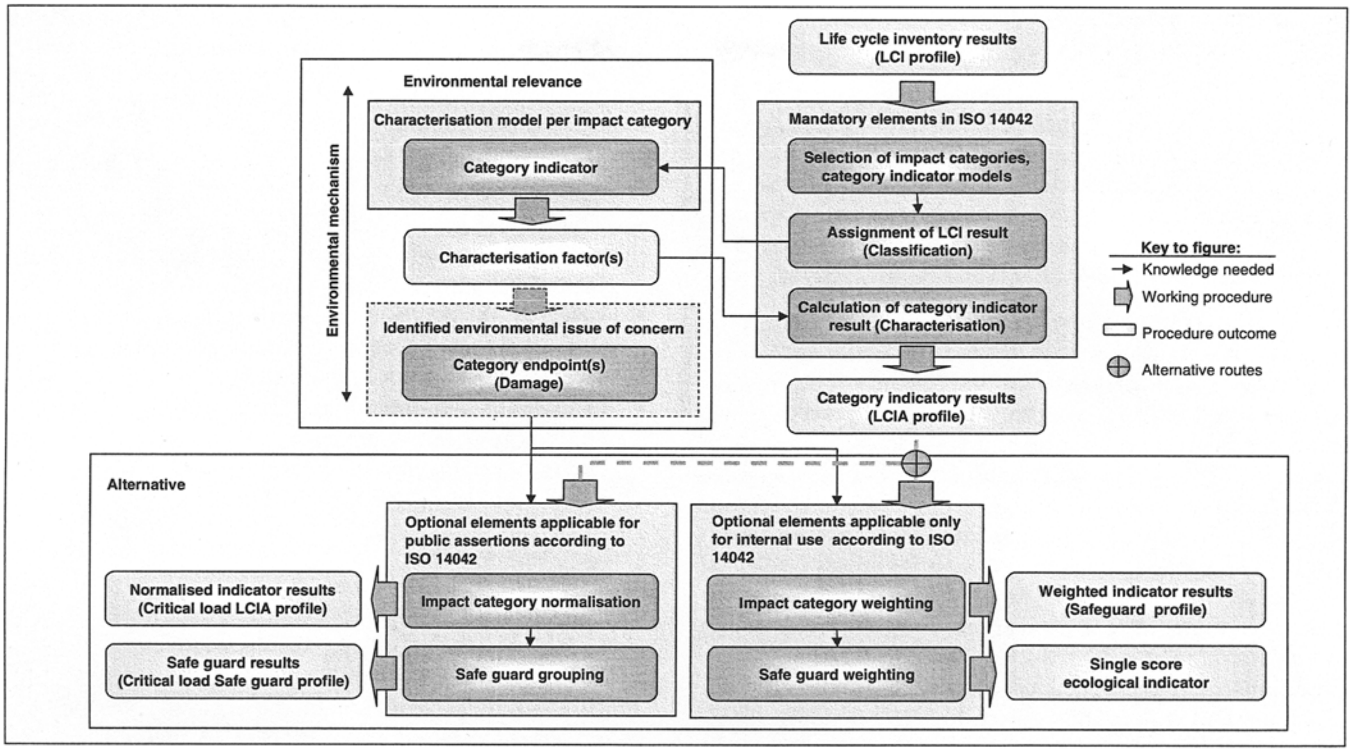

Fig. 6: Two approaches to carry out the optional elements in ISO 14042 and the outcomes are divided according to whether they are applicable for public assertion

A final value choice-based step could then be a weighting across the safeguards, that results in a *single score ecological indicator*. However, the weighted indicator result, and especially the uncertainties in a *single score* ecological indicator, are even more subjective than previous steps and dependent only on human judgements to calculate the weightings. For this reason, neither of these last two value-based steps were found adequate to include in Fig. 3.

By means of the stepwise procedure described above, full transparency of value choices is achieved in the LCIA, as summarised in Fig. 6.

A SWOT analysis is given in **Table 1** where other relevant aspects besides the possibility for public communication are put forward for the EQO normalisation versus a damage approach.

Table 1: SWOT analysis for the EQO normalisation and the damage approach excluding communication aspects

	EQO normalisation approach	**Damage approach**
Strengths	The focus of the EQO is to define the critical load where no adverse effects occur. This corresponds to a situation where the natural and societal interests are congruent. The same spatial and temporal resolution as the damage approach is applicable in the most best available model, with the advantage that the spatial conditions related to the EQO will be independent of time, since a back casing perspective is applied. This makes the approach easy to apply, in particular for long-lived products.	The damage approach attempts to describe the non-linear dose response relation, which is applicable for actual effects in nature. This approach is pointed out as the most adequate way for the mandatory weighting.
Weaknesses	A linearity between zero and the critical load is only commonly justified scientifically by ionising radiation, particle and carcinogenic substances.	Both reliable models and data covering the needed cause effect chains are not yet established, which also affect the impact assessment model. Since boundary conditions change over time, the characterisation model will be time dependent, which makes an assessment of long-lived products problematic.
Opportunities	The needed EQO applies to a pro-active approach where the long time horizon political goals are congruent with the ecological goals. EQO at an impact assessment level is already established for most impact categories.	The opportunity to calculate different effects or potential effects increases the relevance of the model output.
Threats	If the environmental political goals are far from the ecological goals determined by EQO, one of the most important inherent strengths for market acceptance of the approach will disappear.	In the short perspective, the shortage of cause effect models for all impact categories makes a complete impact assessment impossible. The impact assessment model will reduce the model reliability (assigned by applied models and assumptions) and increase ambiguity. In the long run, when concentrations above different threshold are common, the approach is not applicable for risk minimisation.

3 Conclusions

The aim of LCIA, in brief, can be said to give the LCI-profile an environmental dimension and to generate the decision support for further interpretation. A trade-off always exists between distilling the result of an LCIA into as few figures as possible and maintaining environmental relevance. Where an LCA includes comparative issues and the aim is to communicate results publicly, the best available practice here is found to include a normalisation procedure.

The suggested EQO normalisation procedure generates a set of critical loads per impact category, where each is defined by a critical load function and linearity is defined between a zero load and the critical load. This procedure will affect the temporal resolution and the field of application of the LCIA method. The positive aspect is that the suggested normalisation procedure also renders the method applicable for long-lived products like buildings or other infrastructures. This aspect is gained by reducing the damage-oriented resolution. Consequently, for long-lived products where the main environmental loads will appear in the future, it is hard to apply a damage-oriented LCIA method (if all boundary conditions are not assumed to be fixed). The EQO normalisation method will, in this respect, improve the overall reliability of the outcome of an LCA when long-lived products are assessed. Also for short-lived products, the EQO normalisation method will be operational in a proactive perspective, since the method is based on qualities that should be achieved rather than temporary effects based on current situations (back casting technique). In this respect, the EQO normalisation is found to be more pro-active and more realistic to make operational in practice than a damage approach (see Table 1). Strictly applied, a damage-oriented approach working area is not applicable beneath thresholds, in contrast to the EQO normalisation procedure. Adding the fact that source-oriented EQOs are part of the international political agenda – such as emission targets related to different impact categories – the EQO normalisation procedure has the inherent possibility to make political environmental goals operational within LCM tools.

The characterisation model in an LCIA method can be the same, independent of which of the two approaches are used, as long as no integration of category indicators are performed. For this reason, the same spatial resolution is recommended to be used according to best available practice. The difference instead lies in how the characterisation model is made operational and the further, optional, value-based integration of category endpoints in the damage approach. The suggested EQO normalisation procedure aims at a critical load that forms a common reference for normalisation, and therefore this boundary condition is also used in the characterisation model to generate adequate characterisation factors. In comparison, a damage-oriented approach will have to take account of a scenario that estimates the actual background conditions over the product's entire life cycle and then estimates the integrated effect from an additional environmental load at that specific point. With the spatial limitation in mind, it can be argued that a damage-oriented approach will make the LCIA more vague for long-lived products and hard to make operational.

The normalisation suggested here is based on the following major normative foundations:

- A critical load can be established for each impact category based on EQO
- This critical load is followed up by a critical load function where linearity is defined between a zero load and the critical load
- Based on the precautionary principle, the contribution from an impact category will only be desirable for one safeguard, which streamlines the LCIA-profile
- In order to determine the parties who are allowed to contribute to an environmental impact category, per capita normalisation is undertaken which is preferably based on politically established quota agreements.

4 Further work

This article is part of a joint venture research project with two goals. The first goal focusses on how results from an LCA, in general, can best be communicated irreproachably and the second on how human and ecological toxicity can be implemented based on such an LCIA method. For this reason, a complement paper will be produced where the described EQO normalisation procedure is exemplified in a case study, with special interest on assessment of chemical substances.

Acknowledgement. This paper is supported by the Swedish EPA and Swedish Wood Preservation Institute. Special thanks is given to Emma Henningsson at IVL for fruitful comments on the manuscript of this paper and constructive comments from both reviewers.

References

Altenstedt J, Pleijel K (2000): An alternative Approach to Photochemical Ozone Creation Potentials Applied under European conditions. J. Air and Waste Manage. Assoc. 50:1023-1036

Brent AC (2002): Developing country-specific impact categories: Human health and ecosystem quality as criteria for resource quality and availability. Precentation abstract and slides presented at 'InLCA-LCM 2002' housed by ACLCA, http://www.lcacenter.org/lca-lcm/session-methods.html, accessed November, 2002

Consoli F et al. (1993): Guidelines for Life-Cycle Assessment: 'A Code of Practice'. Edition 1, from the SETAC Workshop held at Sesimbra, Portugal 31 March to 3 April, SETAC Brussels

GEDnet (2002): Environmental Product Declarations Network, http://www.environdec.com/GEDNet/, accessed May, 2002

Erlandsson M (2000): Weighting of different impact categories based on a vision of the sustainable society – The Swedish environmental quality goals (in Swedish). IVL Swedish Environmental Research Institute, report No B 1385, Stockholm

Erlandsson M (2001): Significant environmental aspects and environmental goals based on LCA calculation. Report for the Swedish building environmental plan. (in Swedish). IVL Swedish Environmental Research Institute, Stockholm, report No

A20148, revised version, Stockholm, March 2001. (Available at: http://www.kretsloppsradet.com/miljoutredning.html)

ExternE (1995): Externalities of Energy, Volume 1-6. European Commission, Directorate-General XIII, Science Research and Development. European Commission EUR 16520 EN Luxembourg

ExternE (1997): Core Project, Extension of the Accounting Framework; Final Report, compiled by Mayerhofer P, Krewitt W, Friedrich R (1997): The European Commission, Contract No. JOS3-CT95- 0002, Stuttgart (available at http://externe.jrc.es/meth2.pdf)

European Environment Agency (2002): EEA-STAR database http://www.77.eea.eu.int, accessed May, 2002

EU (2001a): Green Paper on Integrated Product Policy. Commission of the European Communities. COM(2001) 68 final, Brussels

EU (2001b): Summary of Discussion at the 4th Integrated Product Policy Workshop: Life Cycle Assessment and Eco-design Guidelines, European Commission, Brussels, 22.05.2001

EU (2001c): Directive 2001/81/EC of the European Parliament and of the Council of 23 October – On national emission ceiling for certain atmospheric pollutants

Guinée JB (Ed.) (2002): Handbook on Life Cycle Assessment operational Guide to the ISO Standards. Kluwer Academic Publishers, book series: Eco-Efficiency in Industry and Science: Vol. 7, Dordrecht

Goedkoop MJ, Hoffstetter P, Müller-Wenk R, Spriensma R (1998): The Eco-Indicator 1998 Explained. Int. J. LCA 3 (6) 352–360

Goedkoop M, Spriensma R (2000): The Eco-indicator 99, A damage oriented method for Life Cycle Impact Assessment. Methodology Report, second edition, PRé Consultants B.V, Amersfoort

Grennfelt P, Moldan F, Alveteg M, Warfvinge P, Sverdrup H (2001): Critical loads – Is there a need for a new concept? Water Air and Soil Pollution Focus 1, 1–7

Grennfelt P, Thörnelöf E (Ed) (1992): Critical Loads for Nitrogen. Report from a workshop held at Lökeberg, Sweden, 6–10 April 1992. Nordic Council of Ministers, Copenhagen

Hauschild M, Potting J (2001): Guidelines on spatial differentiation in life cycle impact assessment – The EDIP2000 methodology. Final draft. Institute for Product Development, Technical University of Denmark (manuscript)

International Standardisation Organisation (1997): Environmental management – Life cycle assessment – Principles and framework (ISO: 14040:1997)

International for Standardisation Organisation (1998): Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis (ISO: 14041:1998).

International for Standardisation Organisation (2000a): Environmental management – Life cycle assessment – Life cycle impact assessment (ISO: 14042:2000)

International for Standardisation Organisation (2000b): Environmental management – Life cycle assessment – Life cycle interpretation (ISO: 14043:2000)

International for Standardisation Organisation (2001): Proposed Draft Technical Report 14047, TC 207. Environmental management – Life cycle assessment – Illustrative Examples on How to Apply ISO 14042

LCM (2002): 1st International Conference On Life Cycle Management, Copenhagen, August 26–29, 2001: http://www.lcm2001.org/, accessed April, 2002

Murray CHJL, Lopez AD (Ed) (1996): The Global Burden of Disease, Volume I of Global Burden of Disease and Injury Series, WHO / Harvard School of Public Health / World Bank, Harvard University Press, Boston

Nilsson J, Grennfelt P (Ed) (1988): Critical Loads for Sulphur and Nitrogen. Critical Loads for Nitrogen. Report from a workshop held at Stockholm, Sweden, 19–24 March 1988. NORD Miljørapport 1988:15, Nordic Council of Ministers, Copenhagen

Scmitz S, Paulini I (1999): Bewertung in Ökobilanzen, Version '99 (English summary). Texte 92/99, Umwelt Bundes Amt, Berlin

Steen B (1999): A systematic Approach to Environmental Priority Strategies in Product Development (EPS). Version 2000 – Methods and Data of the Default Method. Technical Environmental Planning, Chalmers University of Technology, CPM report 1999:5, Gothenburg

Steen B, Ryding S-O (1992): The EPS enviro-accounting method. IVL Swedish Environmental Research Institute, Stockholm, Report No B1080, Gothenburg

Stranddorf HK, Hoffmann L, Schmidt A (2001): Guideline in normalisation and weighting – Choice of impact categories and selection of normalisation references. dk-Teknik, Energy and Environment

MSR (2000): Requirements for Environmental Product Declarations, EPD. An Application of ISO TR 14025 Type III Environmental Declarations. Swedish Environmental Management Council AB, MSR 1999:2. (English translation – Draft version 1)

Swedish Government (2001): Swedish environmental goals – sub goals and action strategies (in Swedish). Prop. 2000/01:130, Stockholm

Udo de Haes H, Lindeijer E (2001): The Areas of Protection in Life Cycle Impact Assessment. Areas of Protection, final draft chapter. (Available at the Internet-Forum 'Global LCA Village' http://www.scientificjournals.com/sj/globallcavillage/welcome.htm)

Udo de Haes H, Jolliet O (1999): How does ISO/DIS 14042 on Life Cycle Impact Assessment Accommodate Current Best Available Practice. Int. J. LCA 4 (2) 75–80

Udo de Haes H, Jolliet O, Finnveden G, Hauschild M, Krewitt W, Müller-Wenk R (1999): Best available Practice Regarding Impact Categories and Category indicators in Life Cycle Assessment. Background Document for the Second Working group on Life Cycle Impact Assessment of SETAC-Europe. Part 1: Int. J. LCA 4 (2) 66–74, Part 2 Int. J. LCA 4 (3) 167–174

Wenzel H, Hauschild M, Alting L (1997): Environmental Assessment of Products. Volume 1: Methodology, tools and case studies in product development. Institute for Product development, Danish Technical University, Ministry of Environment and Energy, Confederation of Danish Industries, Chapman and Hall, London

Received: September 16th, 2002
Accepted: January 31st, 2003
OnlineFirst: February 1st, 2003